Beam test performance of the 2S prototype module for the High Luminosity Upgrade of the CMS Strip Tracker

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STFC Rutherford Appleton Laboratory

Imperial College London

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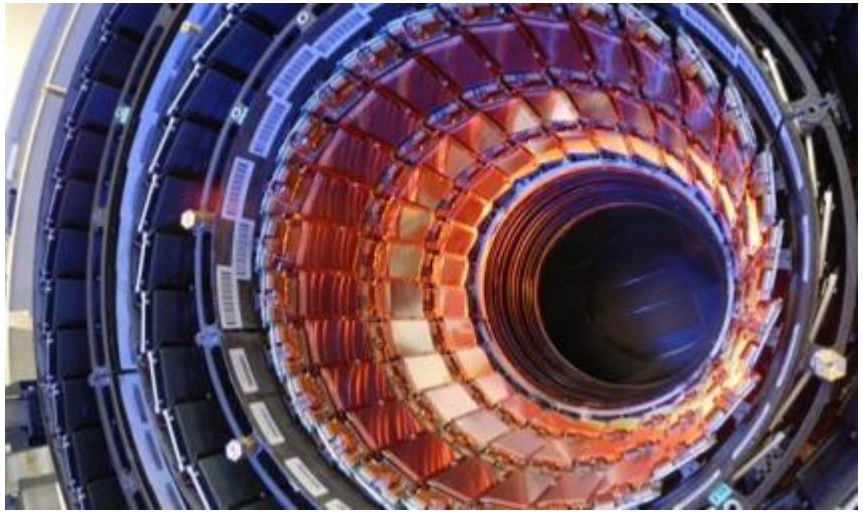
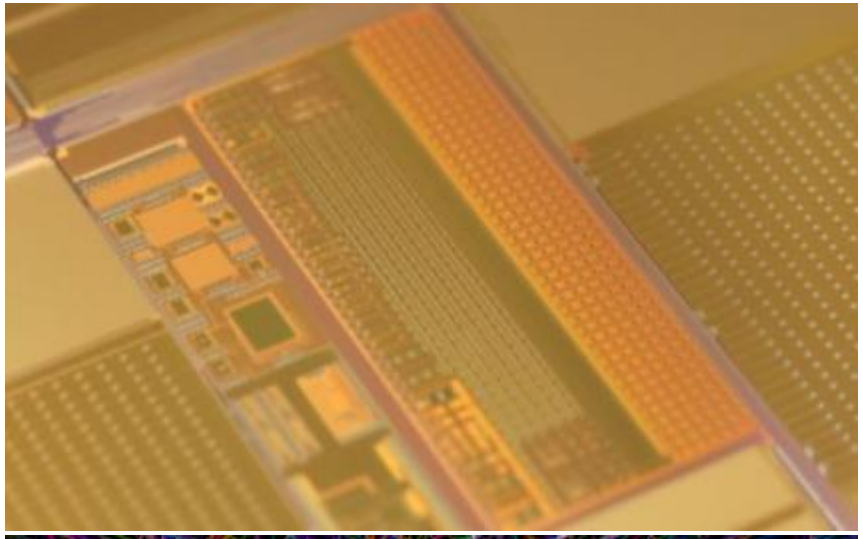
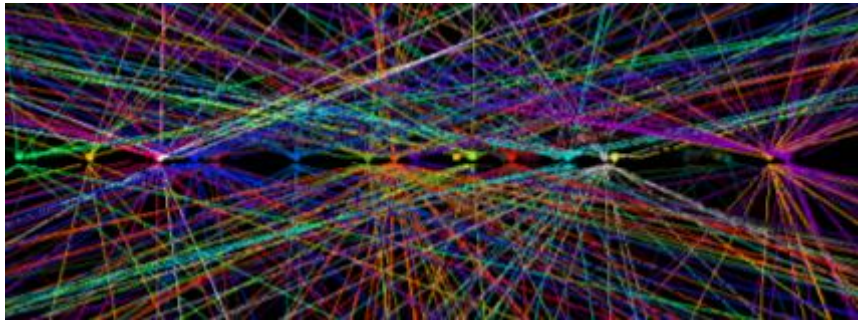
Science & Technology Facilities Council



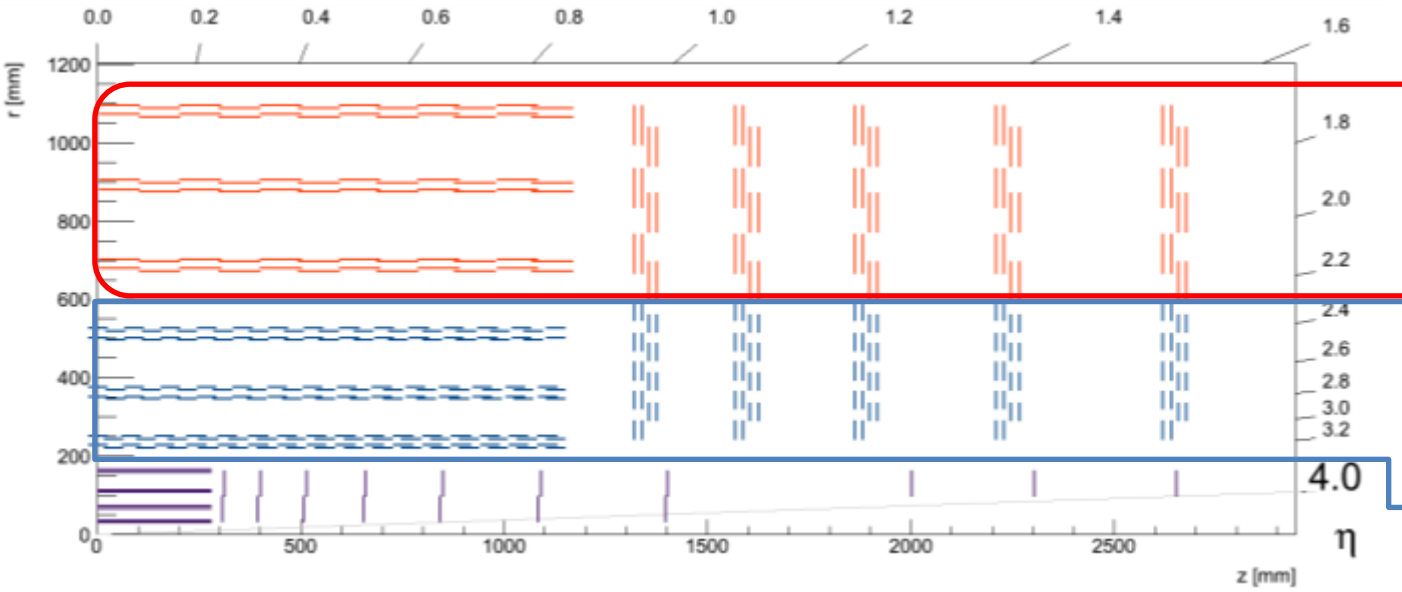


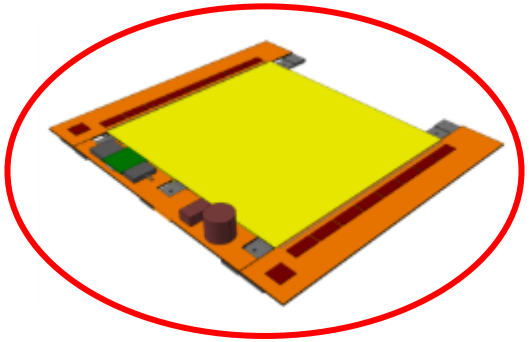


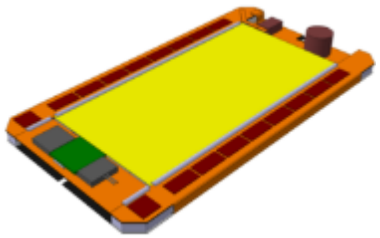
Outline

- Tracker upgrade & detector module
- The CMS Binary Chip 2 (CBC2)
- Mini-2S module design & testing
- DESY test beam
  - Setup
  - Results
- Summary & Conclusion

Phase-II upgrade of the CMS Strip Tracker

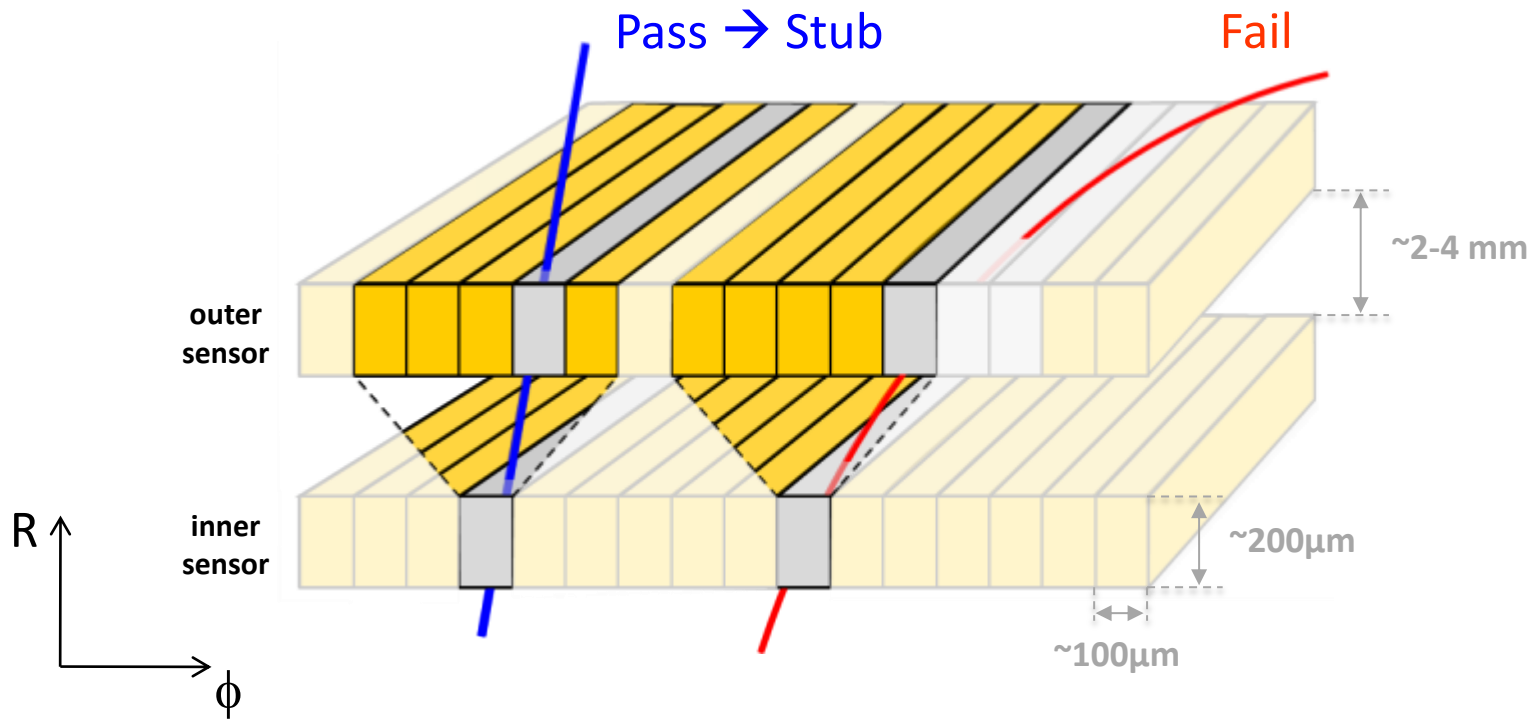






- Baseline design: Barrel+5Endcaps
- Based on 2 module types only
- Provides at the same time:
  - *readout data* upon receipt of L1 trigger
  - *trigger data* @40MHz

Basic trigger module concept



- High-PT tracks (stubs) can be identified if cluster centre in top layer lies within a search window in R-Φ (rows)
- p_T cut given by: module radius (z), sensor separation and correlation window

CBC2 and stub finding logic

CMS Binary Chip (CBC)

2 versions have now been produced - both in 130nm CMOS

CBC1 (2011)

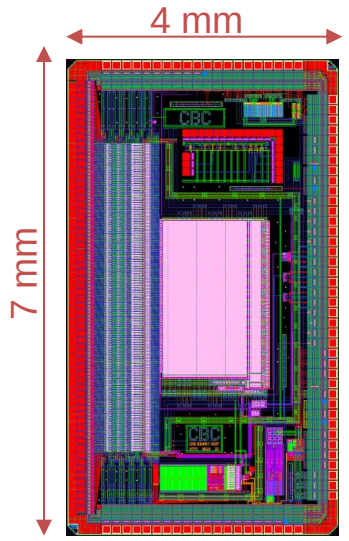
- 128 wire-bond pads, 50 mm pitch
- front end designed for short strips, up to 5 cm
  DC coupled, up to 1mA leakage tolerant, both sensor polarities
- binary unsparsified readout
- pipeline length 6.4 msec

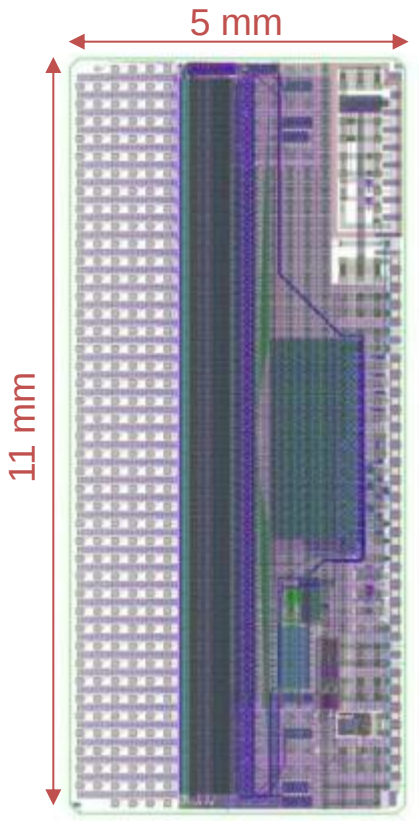
- chip worked well in lab and test beam
- no triggering features

CBC2 (January, 2013)

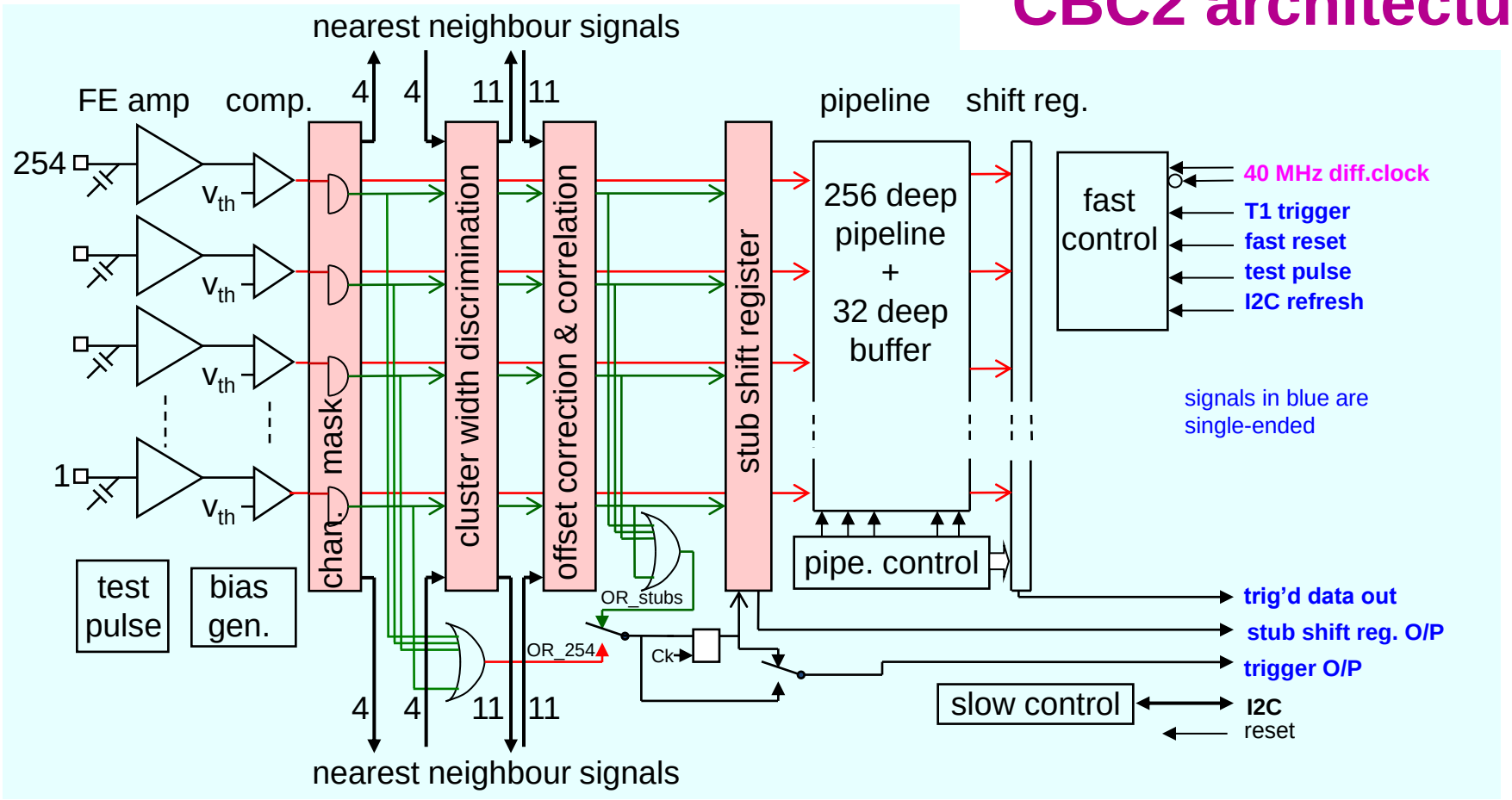
- 254 channels
- ~same front end, pipeline, readout approach as CBC1

- bump-bond layout
- includes triggering features





CBC2 architecture



254 channels:	127 from each sensor layer
channel mask:	block noisy channels from trigger logic
CWD logic:	exclude wide clusters >3
correlation logic:	for each cluster in lower layer look for cluster in upper layer window
trigger output:	1 bit per BX indicates correlation logic found one (or more) stubs
triggered data out:	unsparsified binary data frame in response to L1 trigger

Stub finding logic

Cluster width discrimination (CWD) logic

exclude clusters with hits in >3 neighbouring channels
wide clusters not consistent with high pT track

Offset correction & correlation logic

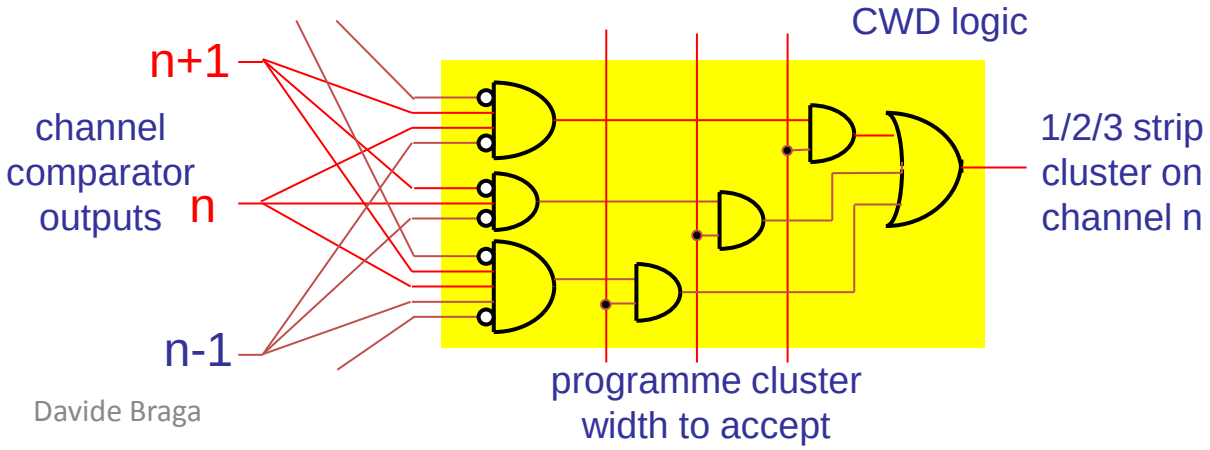
for a cluster in bottom layer, look for correlating cluster occurring in window in top layer

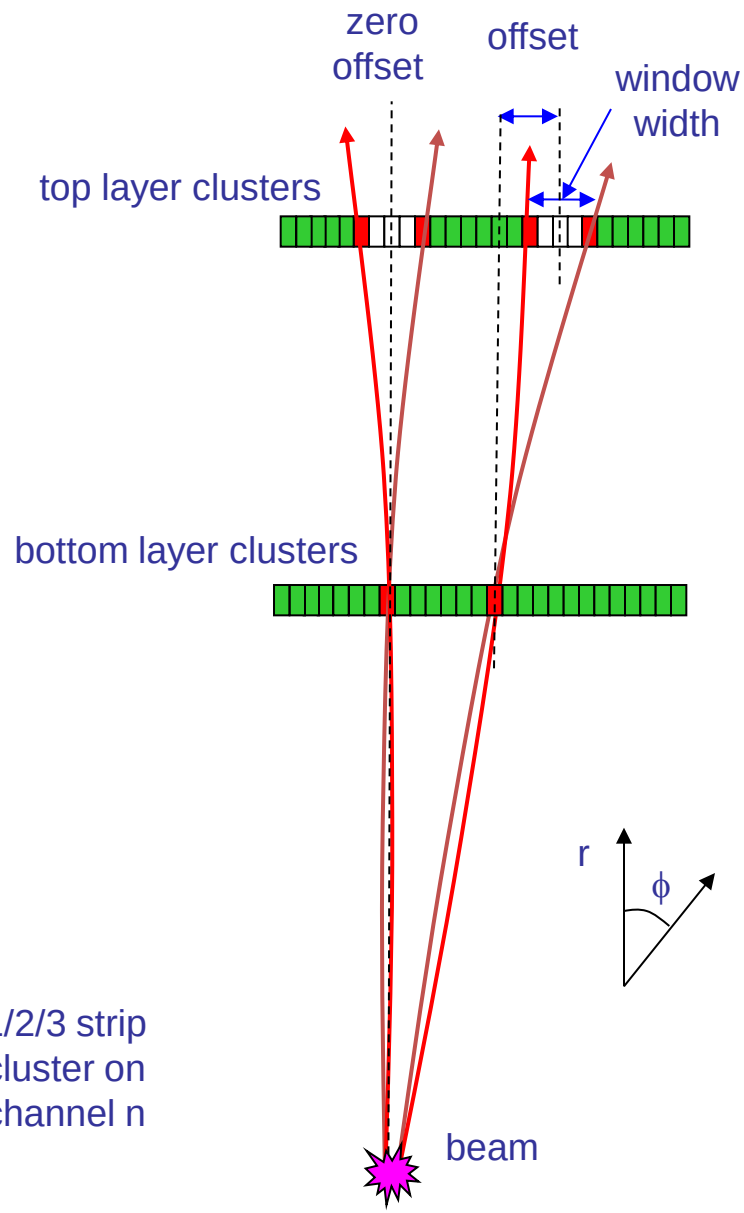
window width controls pT cut

- stub found if cluster in bottom layer corresponds to cluster within window in top layer
- programmable up to ± 8 channels

offset defines lateral displacement of window across chip

- programmable up to ± 3 channels





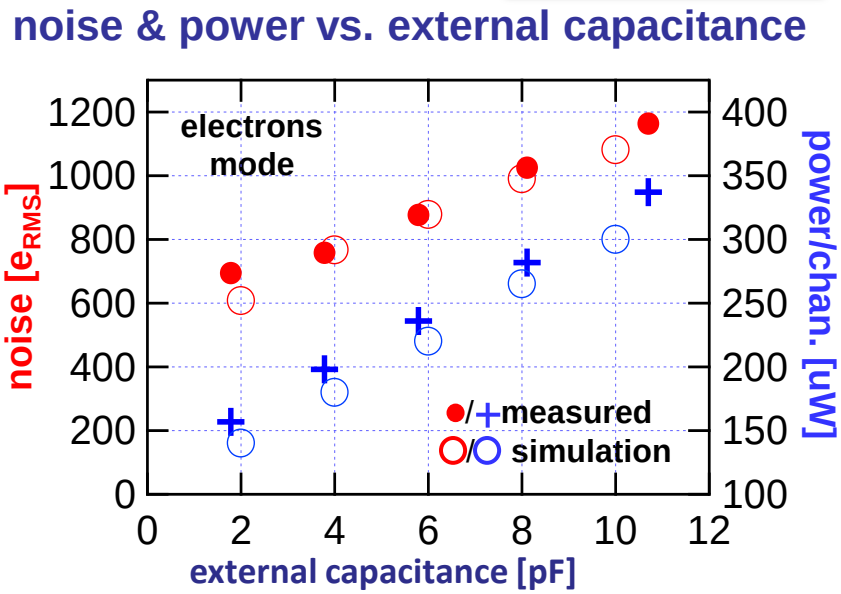
CBC2 performance

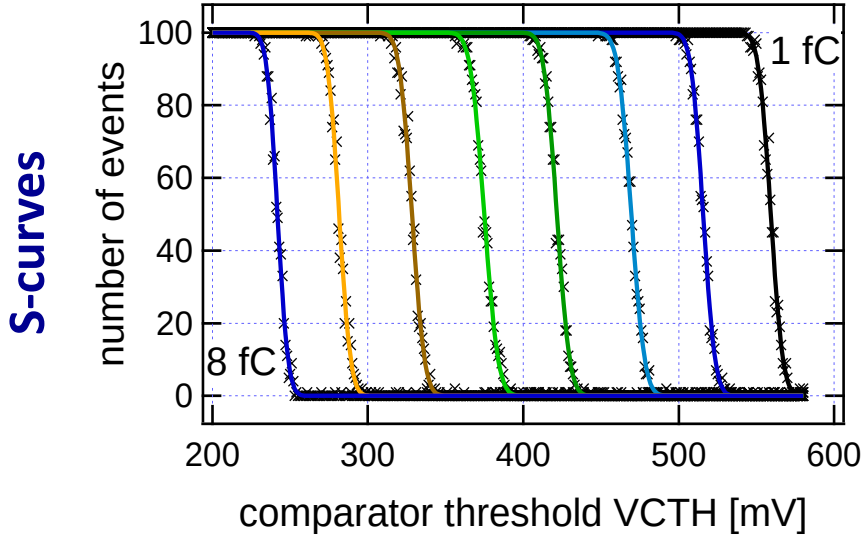
M. Raymond, IC

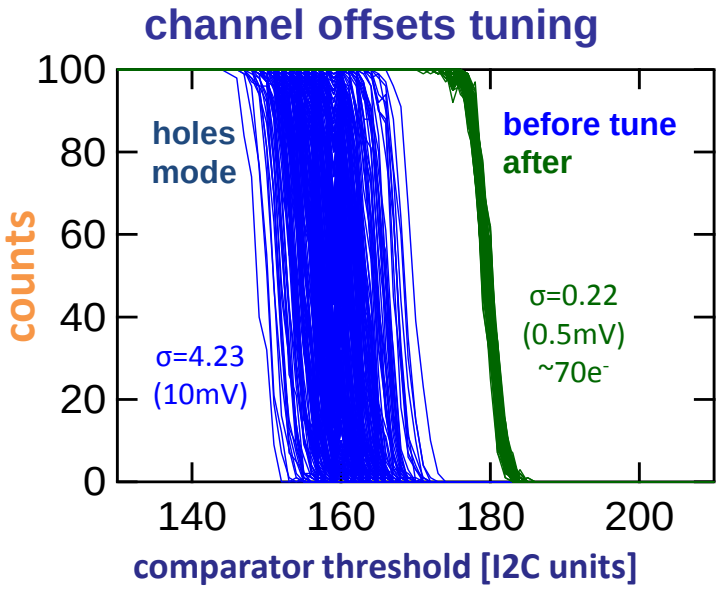
- All core functionality meets requirements
- Correlation functionality verified with test pulses, cosmics (backup), and in test beam
- Analogue performance close to simulation and specifications

  e.g. **1000e** noise for 5 cm strips (~8 pF)

  achievable for total channel power of **350 uW**





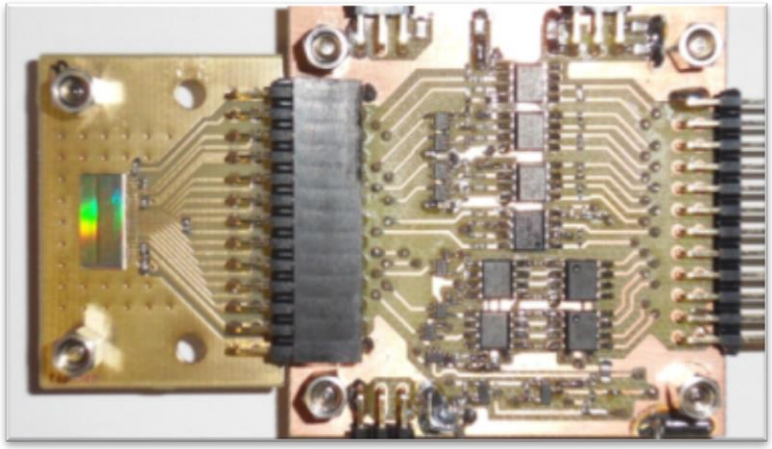


CBC2 Testing Activities

CBC2 testing activities

Wire-bond CBC2

- Useful to develop wafer probe procedures
- X-rays TID testing

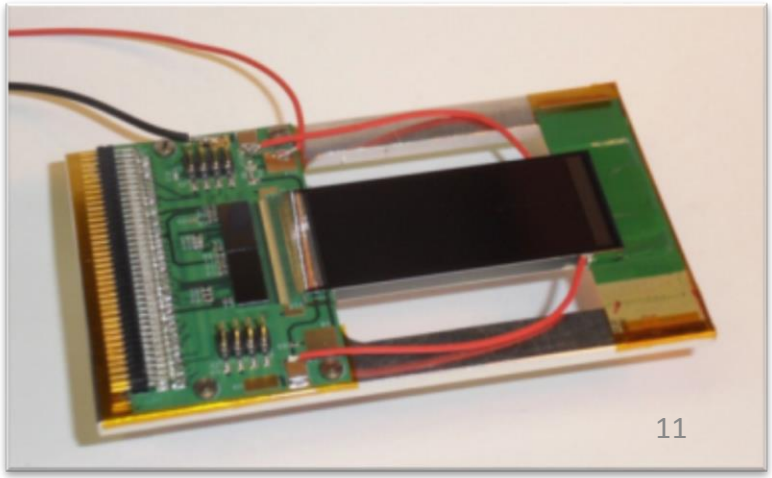


2xCBC2 hybrid

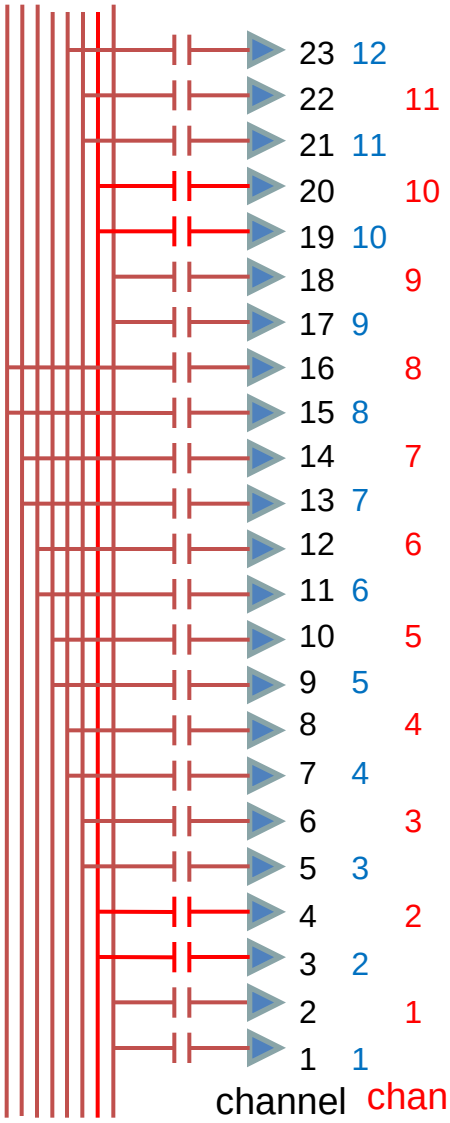
- Hybrid characterization and chip integration
- Bump-bonded ASICs
- Inter-chip links & logic

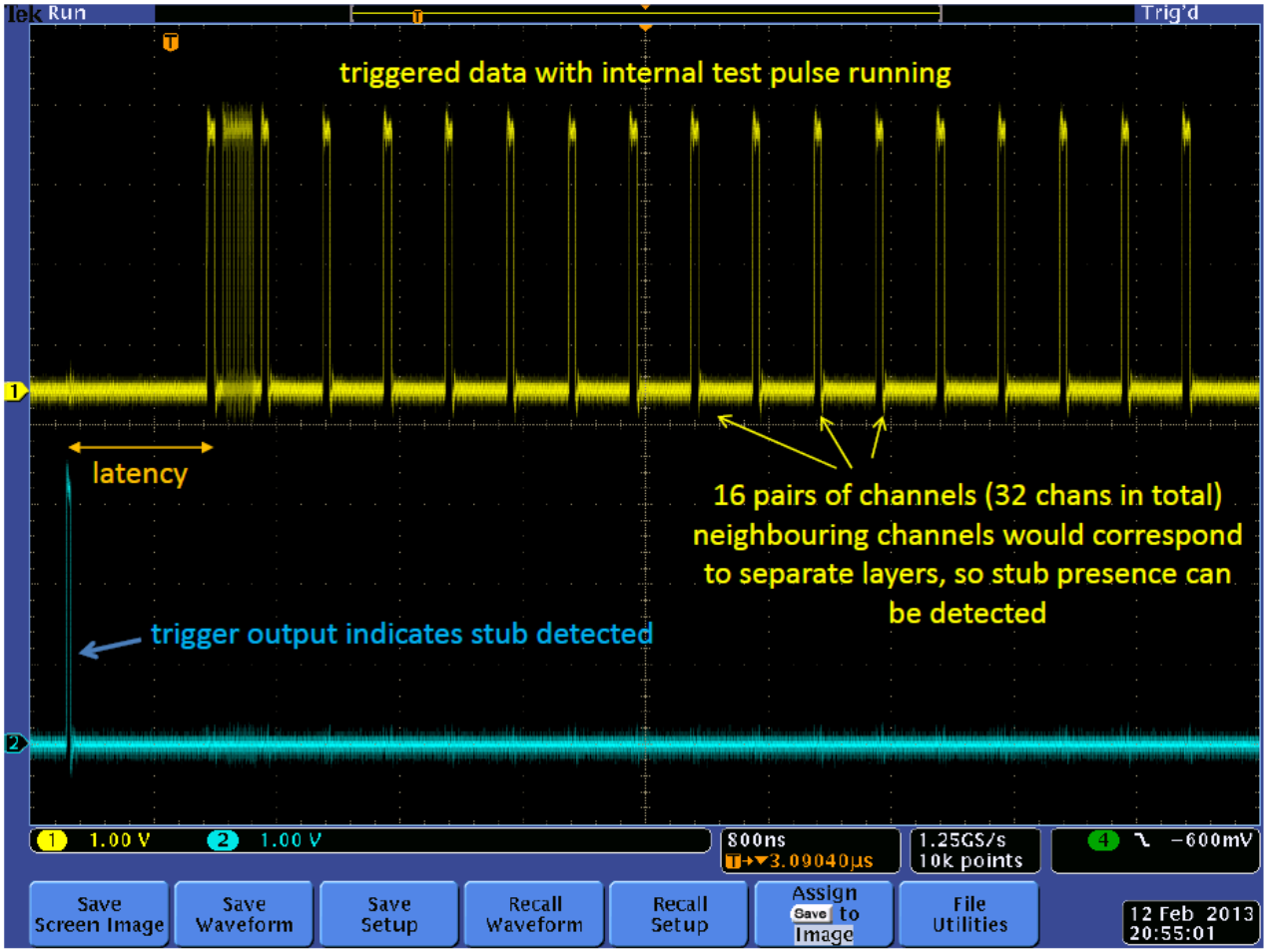
2xCBC2 mini-module + sensor

- Sr-90 source
- Cosmic rays
- Beam Test



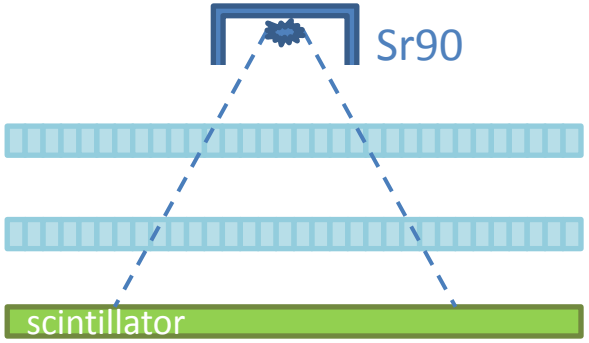
Results with test pulse

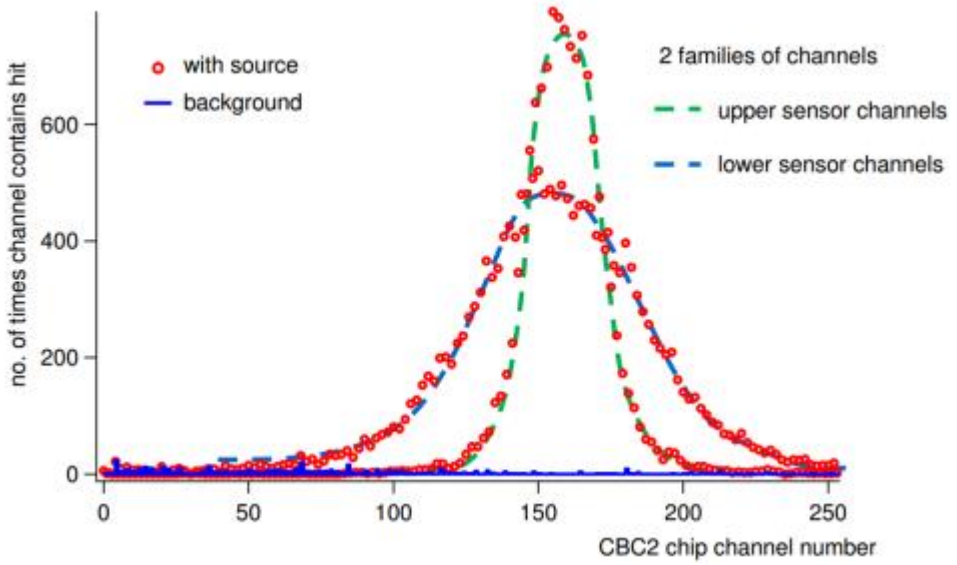


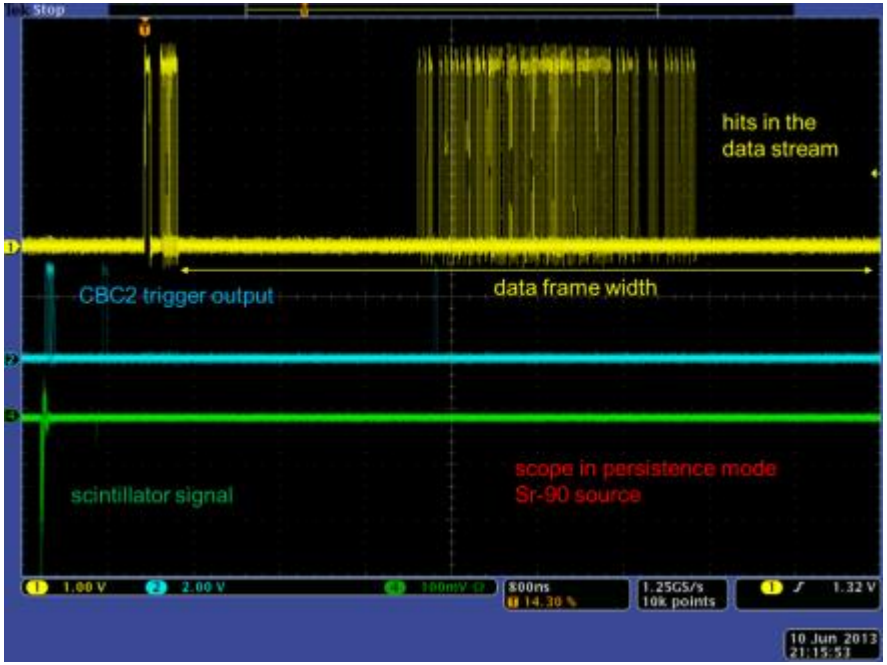


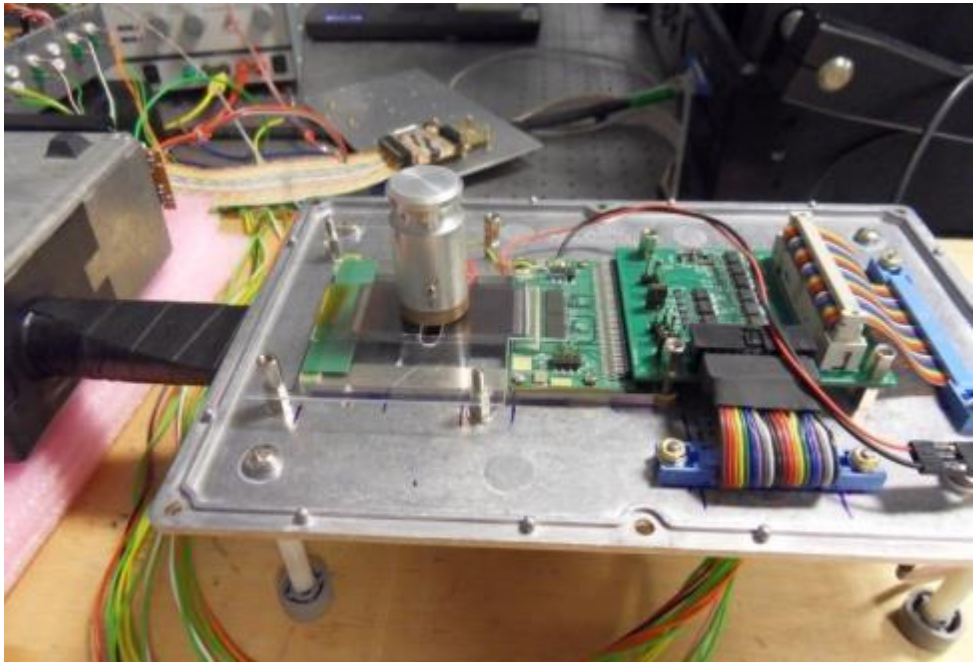
→ Test pulse together with individually-programmable channel masks can be used to fully exercise the coincidence logic

Logic tests using beta source



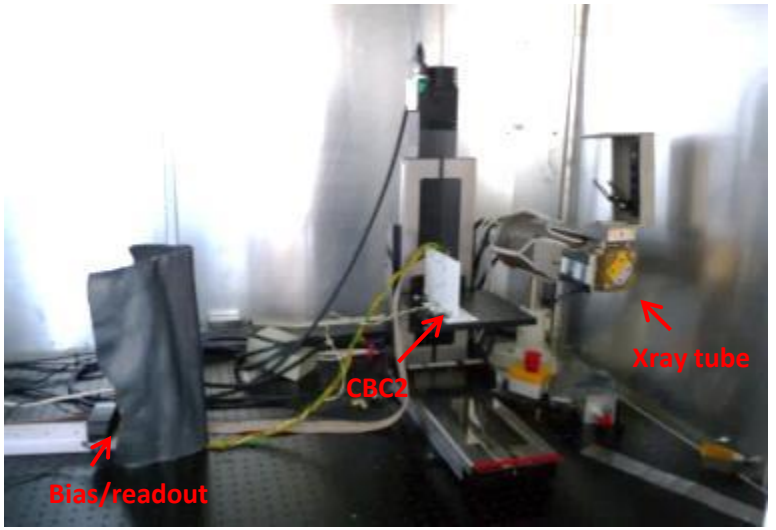


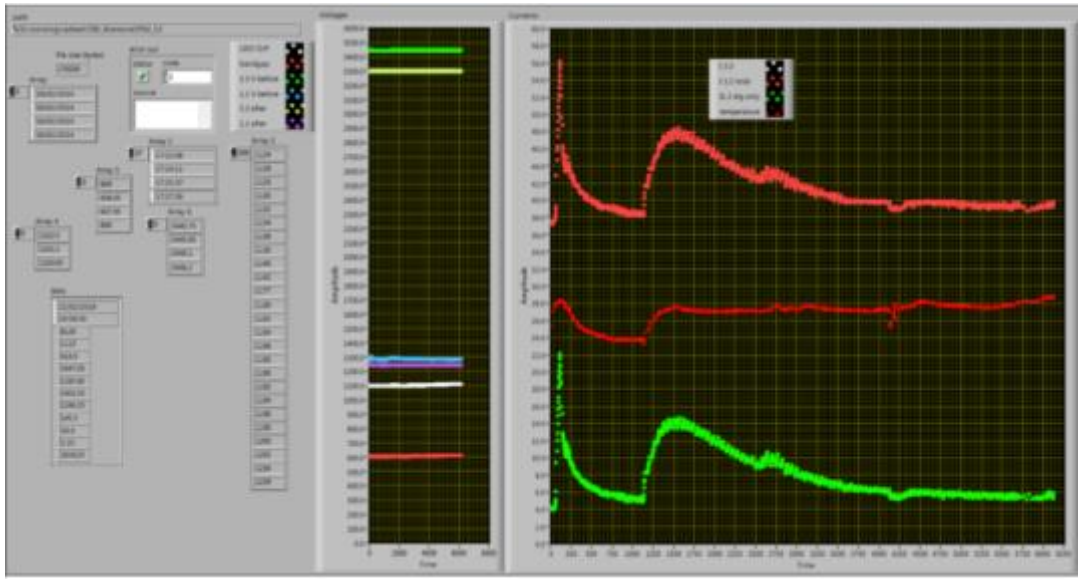




Total Ionizing Dose test

- Initial Xray irradiation to 10 Mrads and 1wk annealing @100°C
- CBC2 operated continuously during irradiation and annealing
- monitored currents, biases, pedestal, noise
- no significant change in performance, moderate increase in current before annealing





Beam Test

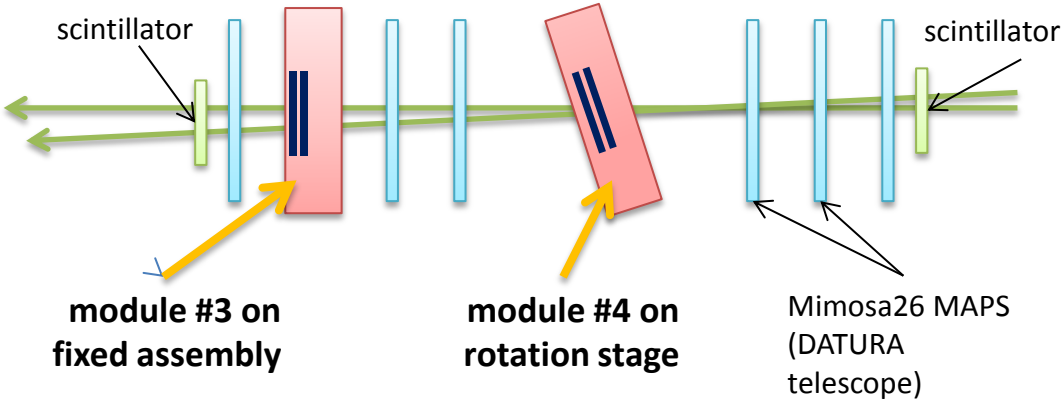
Pt module beam test at DESY

- December 2013
- 4 GeV positron beam
- Datura telescope + 2 pT modules (1 fixed, 1 rotatable) with 2 different strip sensors
- Custom control and DAQ

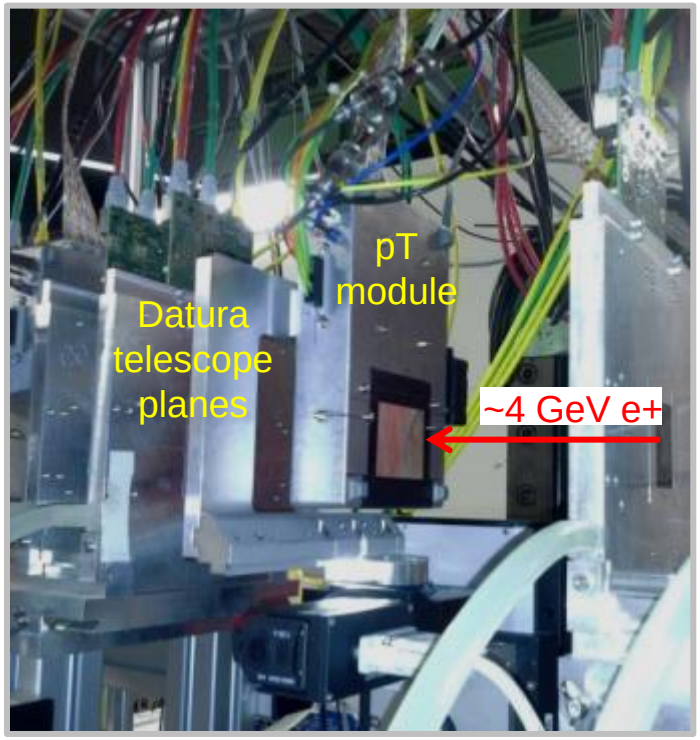
Module #3 (FIXED)
Infineon, n-type
Sensor 80x300 µm
dL = 2.8 mm
Strip length = 50 mm
#channels = 256

Module #4 (DUT)
CNM, p-type
Sensor 90x270 µm
dL = 2.8 mm
Strip length = 54 mm
#channels = 254

positron beam
low angular divergence (small angular error)



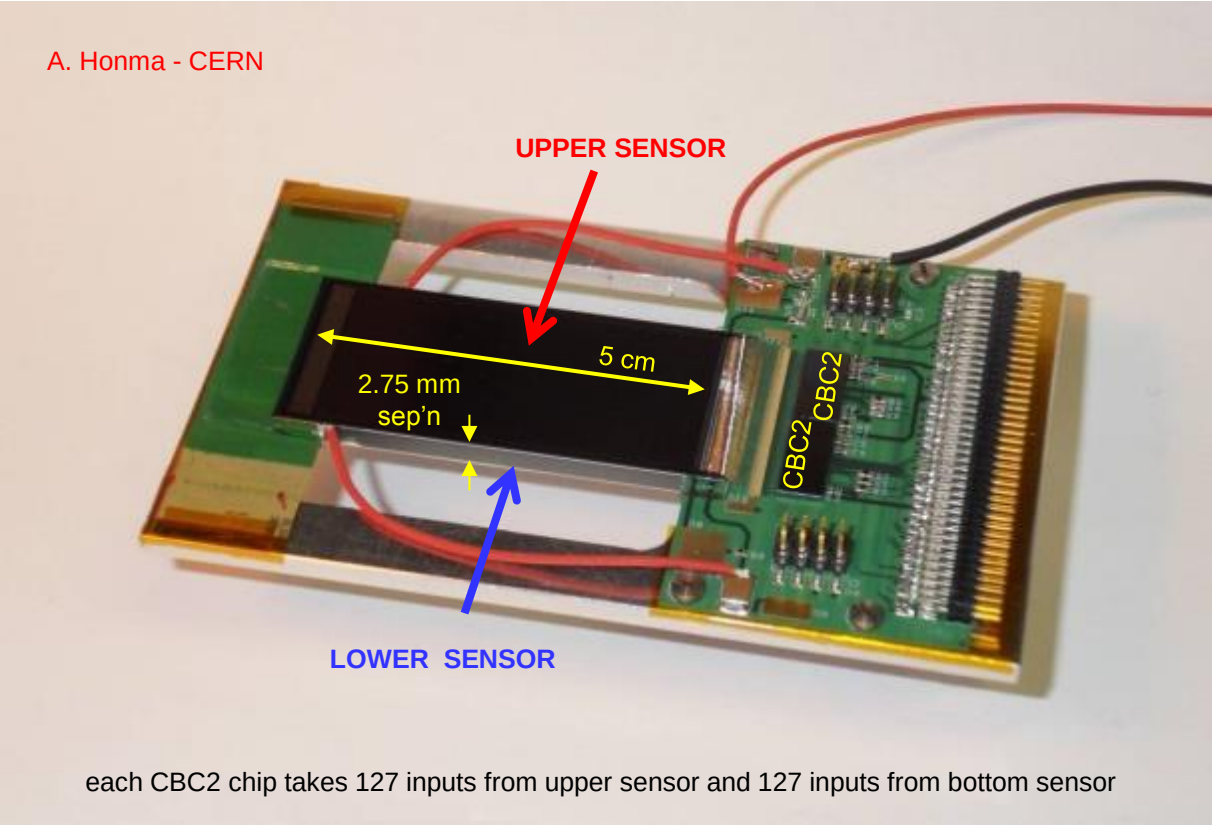
TOP VIEW: strip direction into page



Pt modules & sensor variants

3 PT modules taken to DESY:

- 2 different sensor types
- one module left as backup

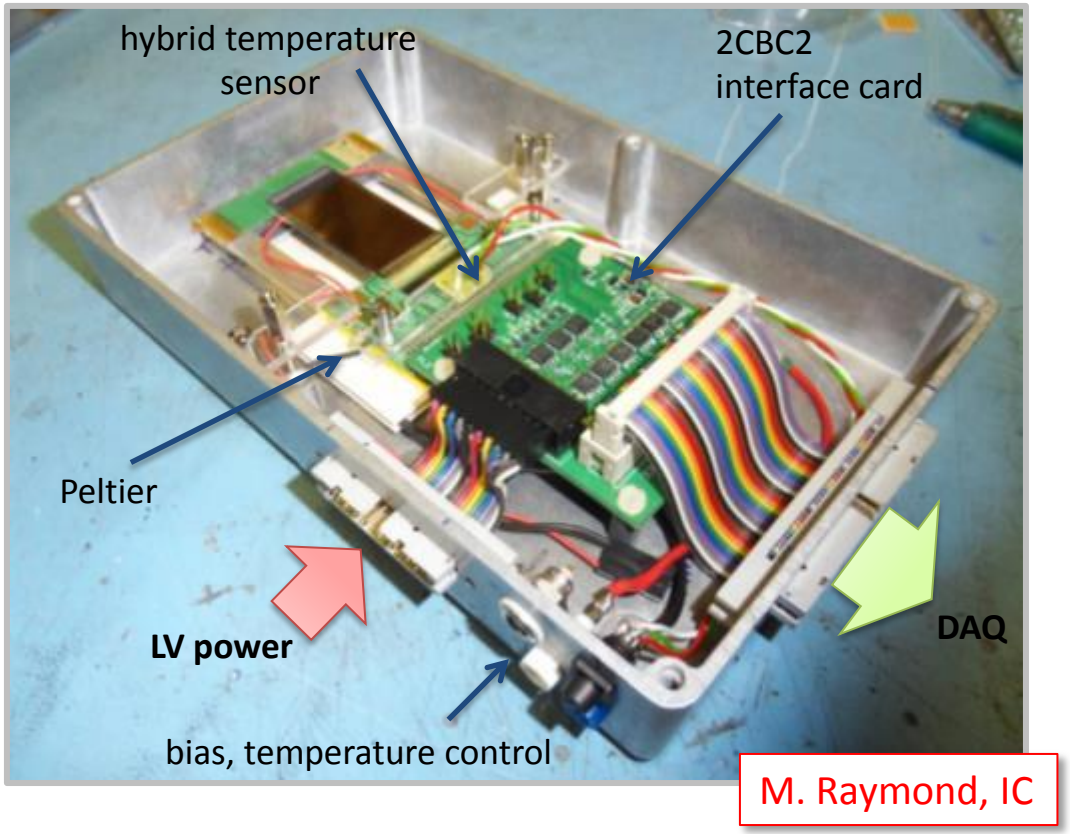


each CBC2 chip takes 127 inputs from upper sensor and 127 inputs from bottom sensor

module #	sensor	sensor type	pitch [um]	thickness [um]	length [mm]	# strips	comments	tested
3	Infineon	n-type	80	300	50	256	region of disconnected channels	yes
4	CNM	p-type	90	270	54	254		yes
1	Infineon	n-type	80	300	50	256	noisy strips, disconnected channels, odd low bias behaviour	no/ backup

Modules taken to DESY

Each module assembled into identical units for mechanical support, environment control & handling



- light-tight aluminium cast ~10x20cm boxes for support and heatsinking

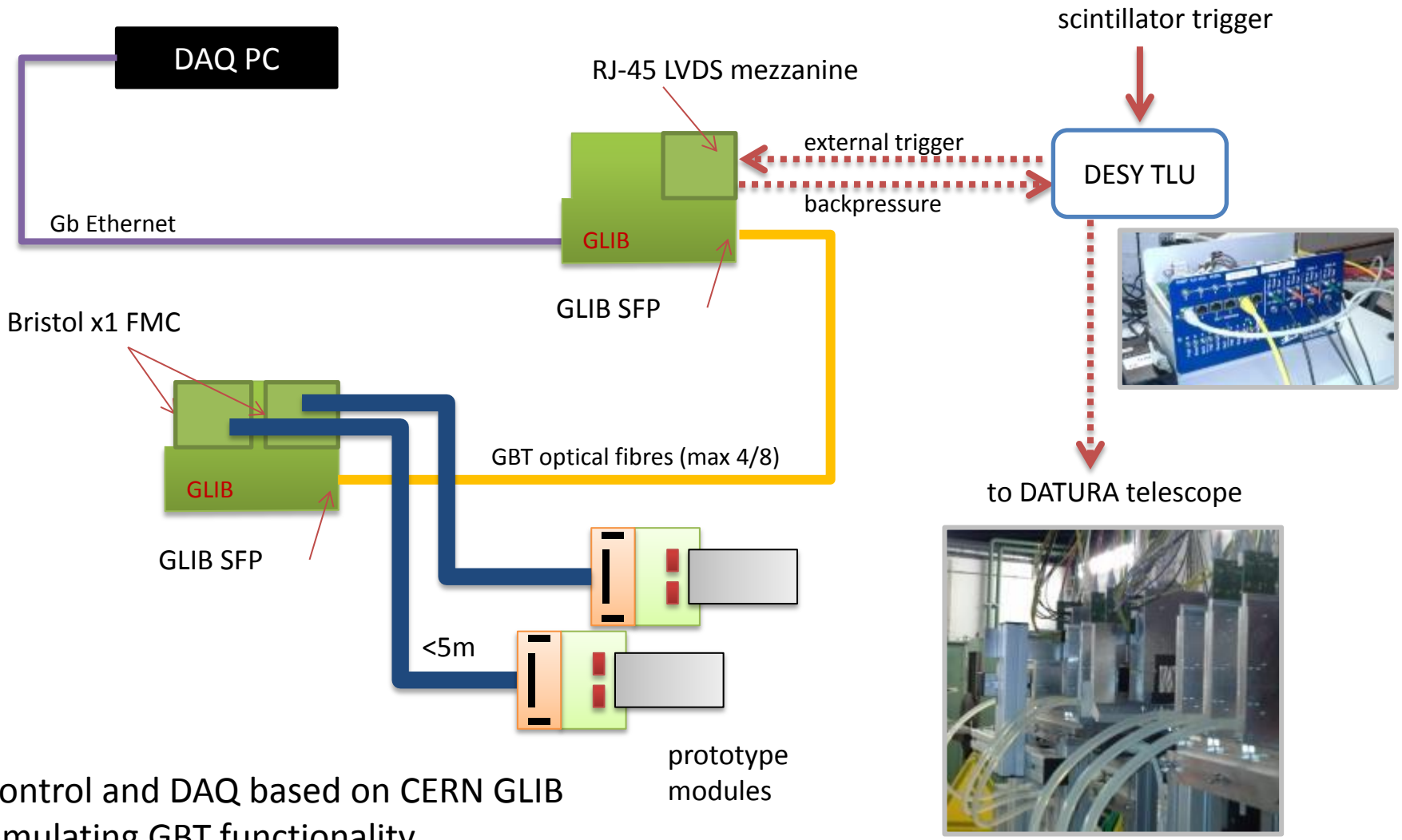
- aluminium foil windows

- Peltier elements to actively cool hybrid to 20° via external Arduino-based controller

- connectors for DAQ, power, temperature control, HV bias

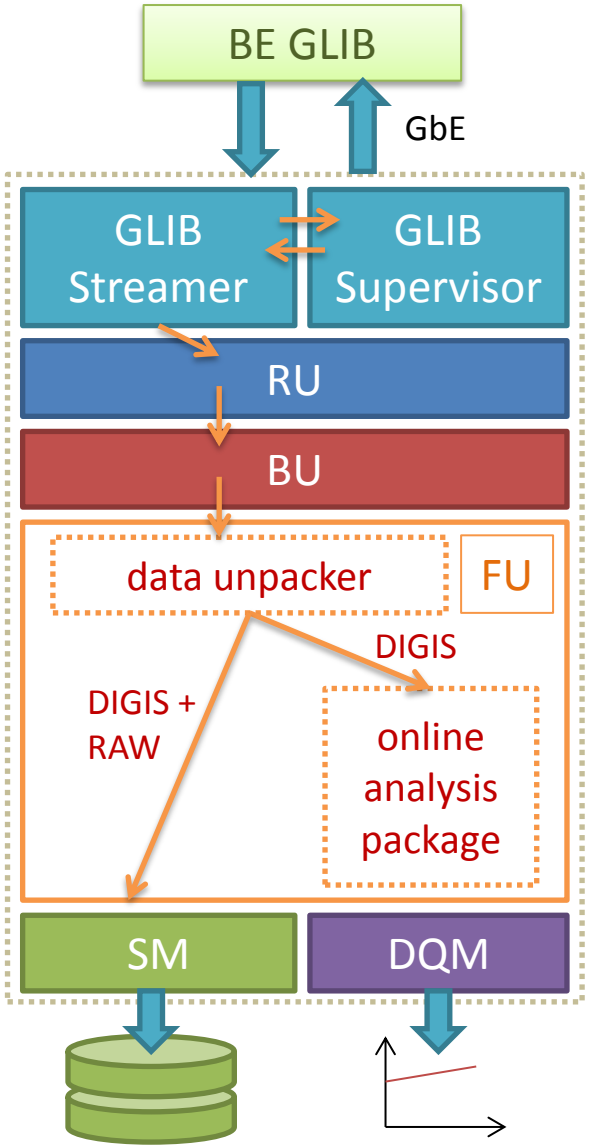
Beam test DAQ

M. Pesaresi, IC
L. Gross, IPHC

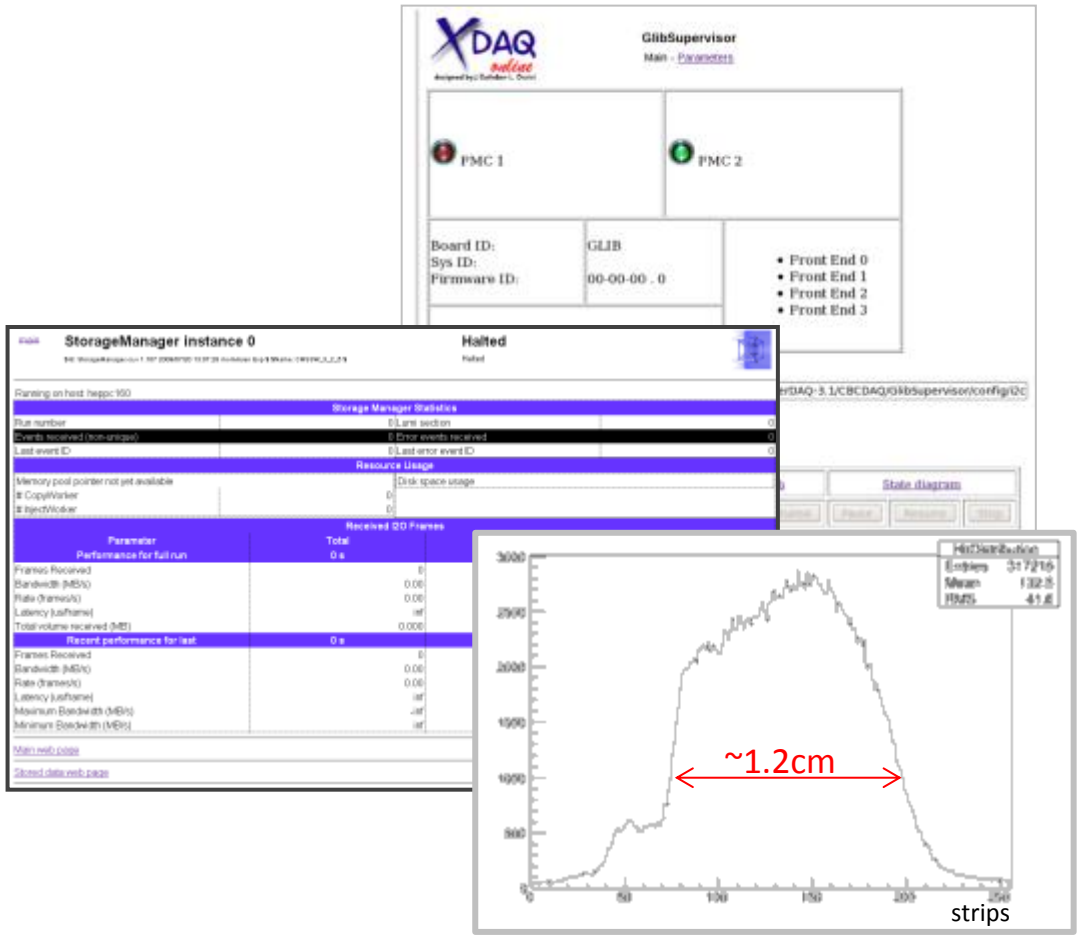


control and DAQ based on CERN GLIB emulating GBT functionality

Beam test DAQ (2)



- basic elements for the CMS based DAQ were put in place just in time for beam test



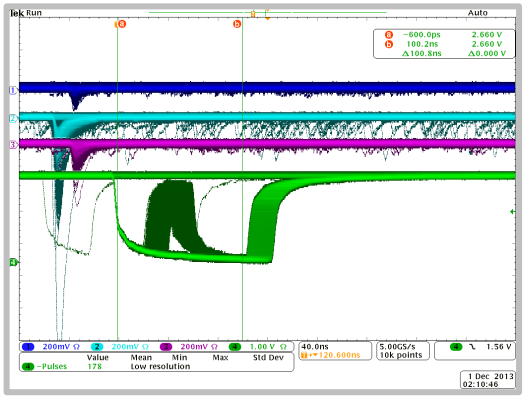
Beam test issues

- most issues solved during week's running:
DAQ ran stably for last few days (albeit at ~300Hz)

- some issues that took a while to solve to do with the external TLU

Timestamp issue with the Datura Telescope:

- BX and Orbit number not saved by the GLibStreamer
- Ali Harb (DESY) looking into ways to synchronise the two data sets based on hit patterns



Commissioning steps

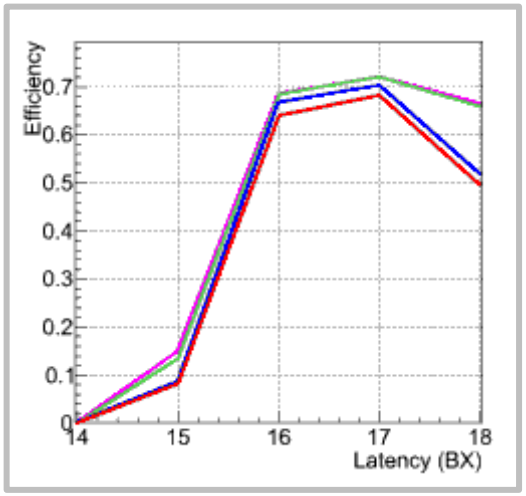
much time was dedicated to commissioning the modules in beam

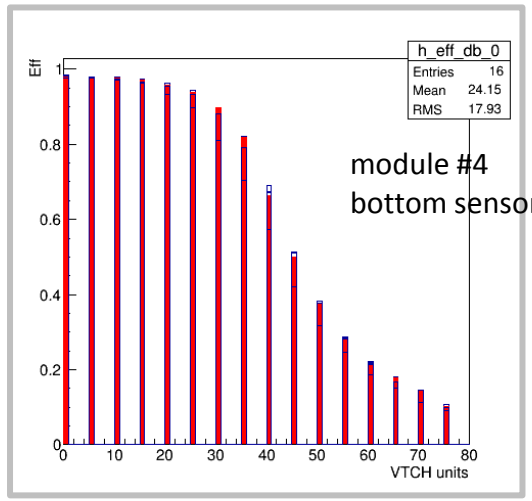
Measurements

- 24h shifts in the last 3-4 days

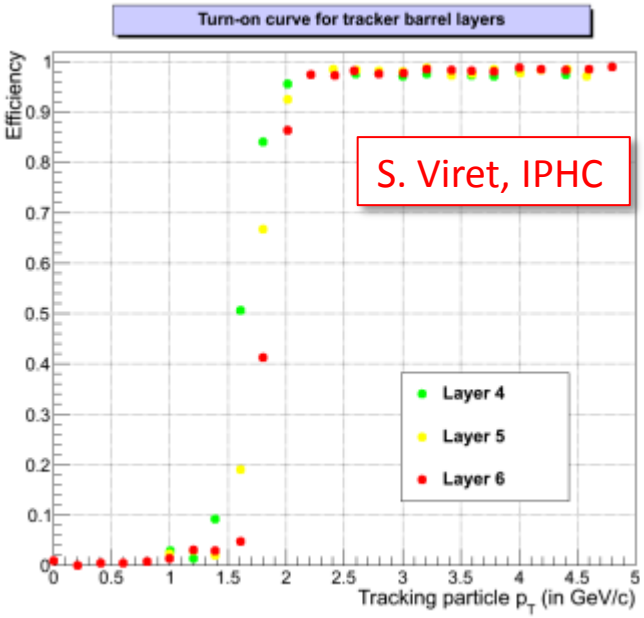
- over 120M events to disk!

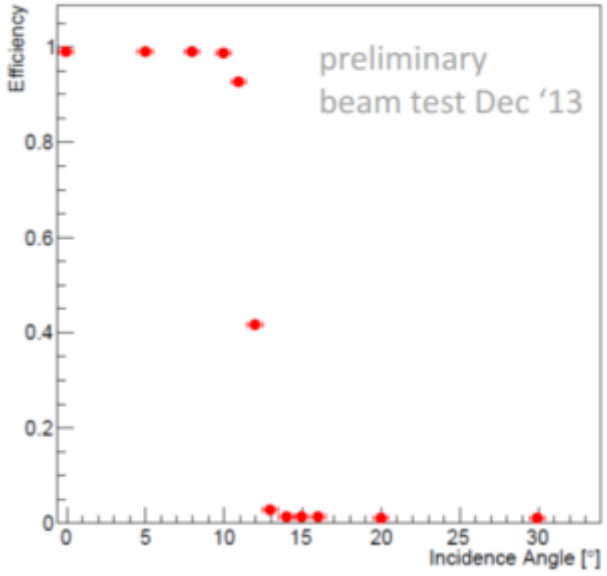
- threshold scans at normal incidence (high statistics, fine VCTH steps)
- low threshold scan (to see noise floor)
- latency scans
- angular scans with high statistics, nominal thresholds
- threshold vs angular scans (low statistics, coarse VCTH steps)
- runs with different cluster width discrimination settings
- dedicated runs to check DAQ and telescope synchronisation

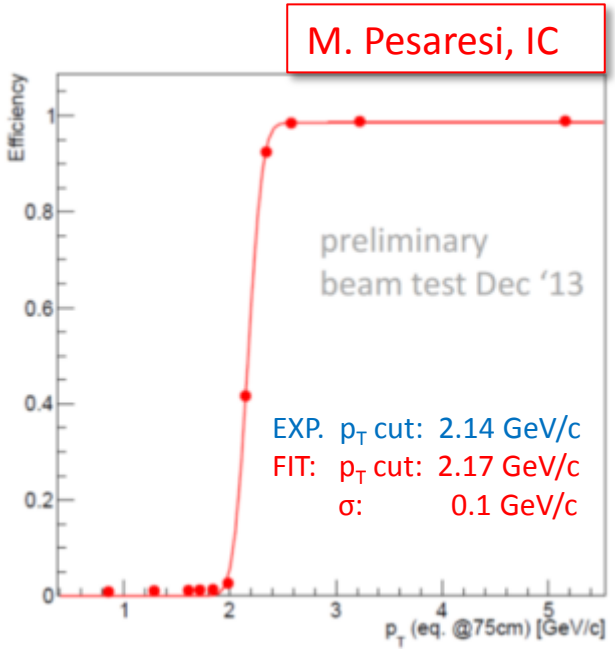




P_T cut principle demonstrated







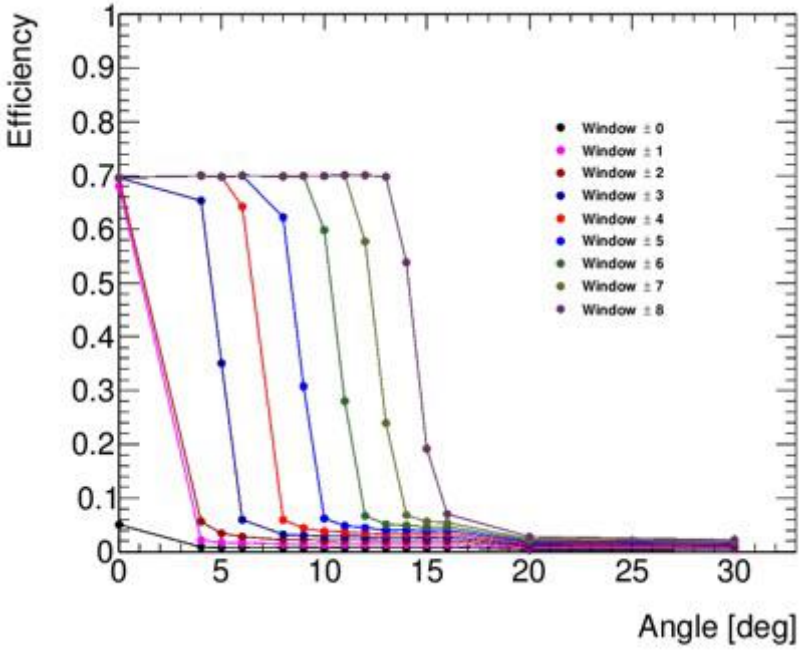
Pt Selection cut: simulation ⇨ **measured efficiency** ⇨ **reconstructed p_T cut of r=75cm layer**

CBC2 correlation window was set to
+/- 7 strips; 0 strip offset

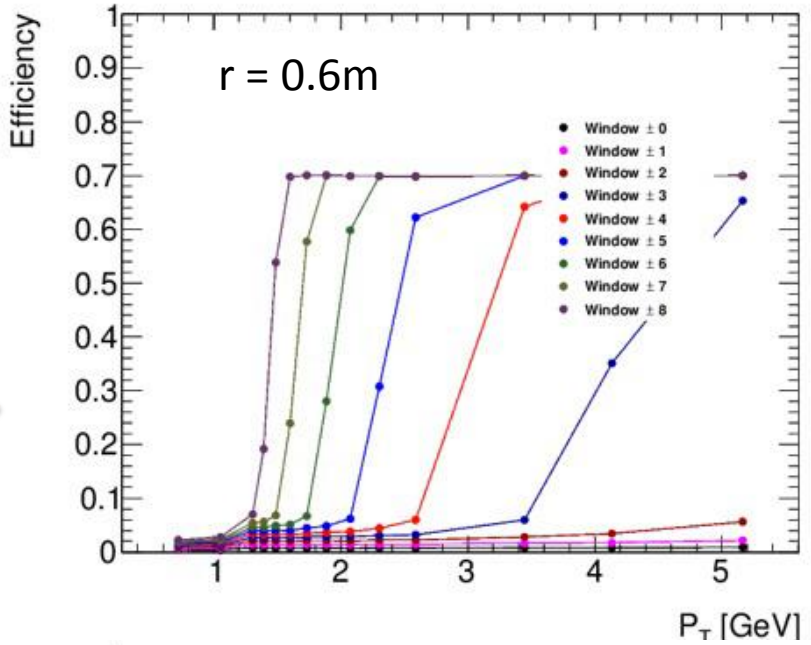
- P_T-cut reconstructed from beam test data matches the design one exactly
- Sharp turn-on

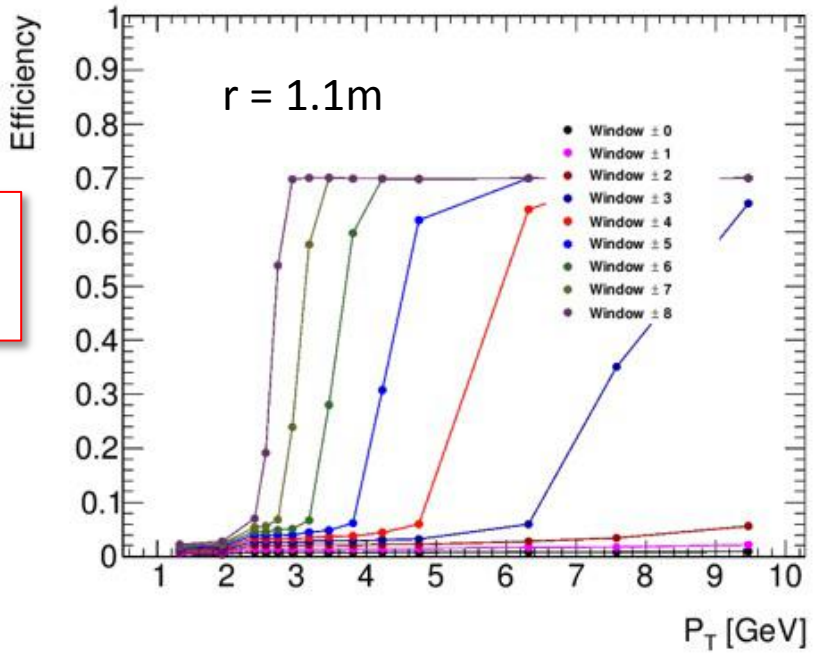
→ **First experimental result to prove the stub selection concept!**

Stub Efficiency vs. Angle



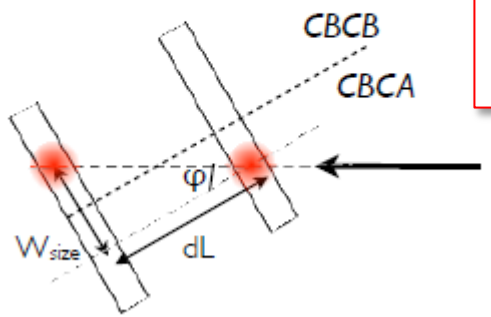
Reconstructed stub Efficiency vs. P_T



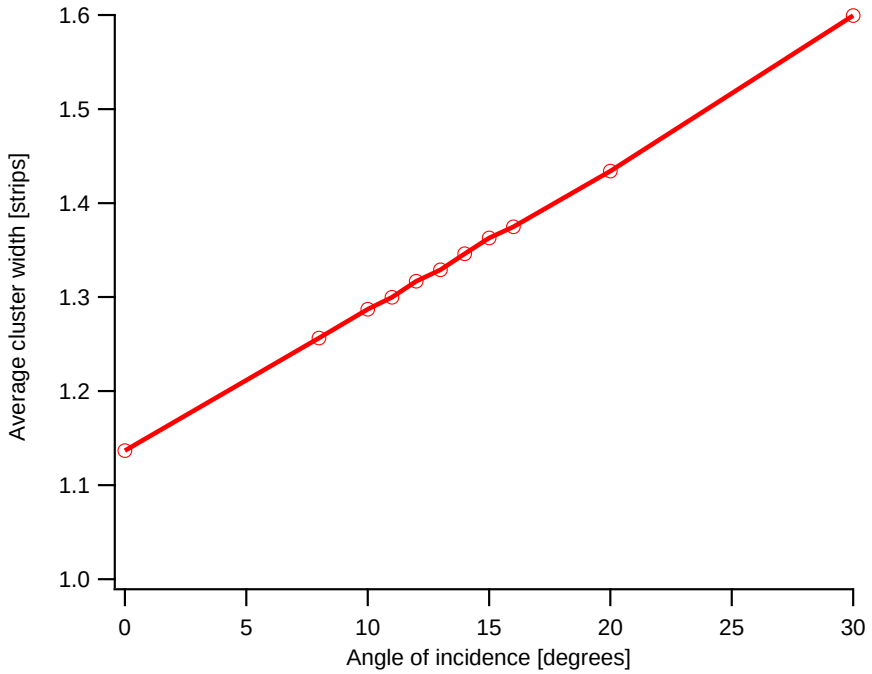


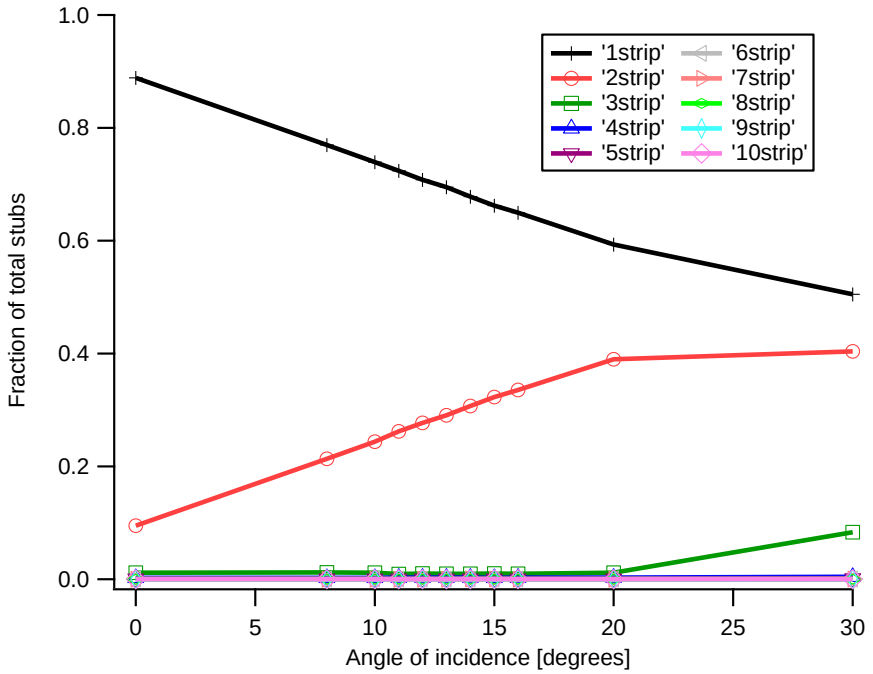
Stub efficiency turn-on angle:

$\varphi = \text{atan}(W_{size}/dL)$



Kirill Skovpen, IPHC

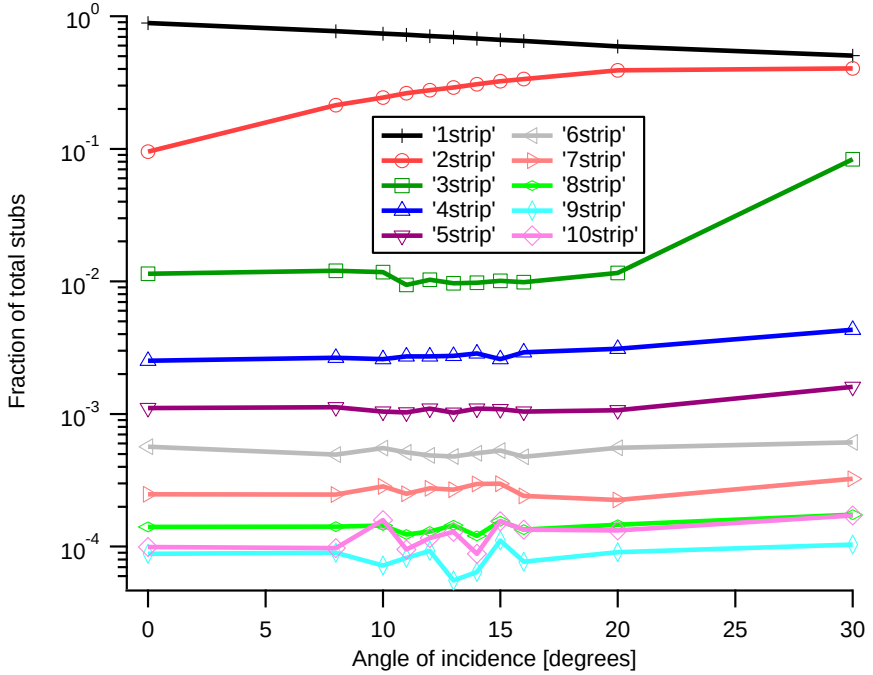




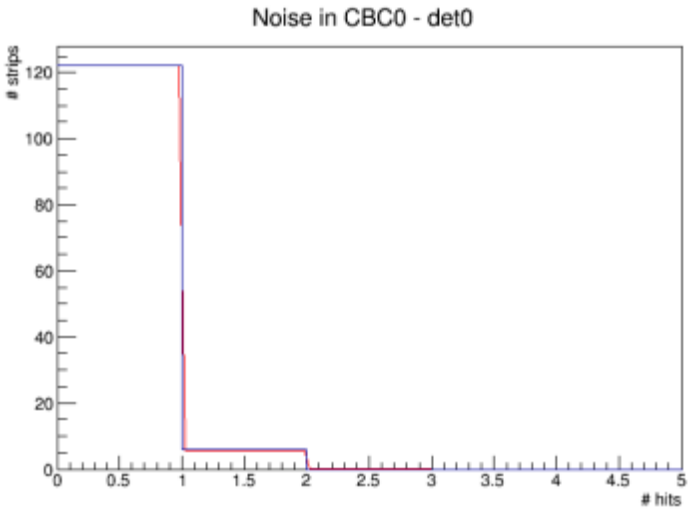
Study of cluster width

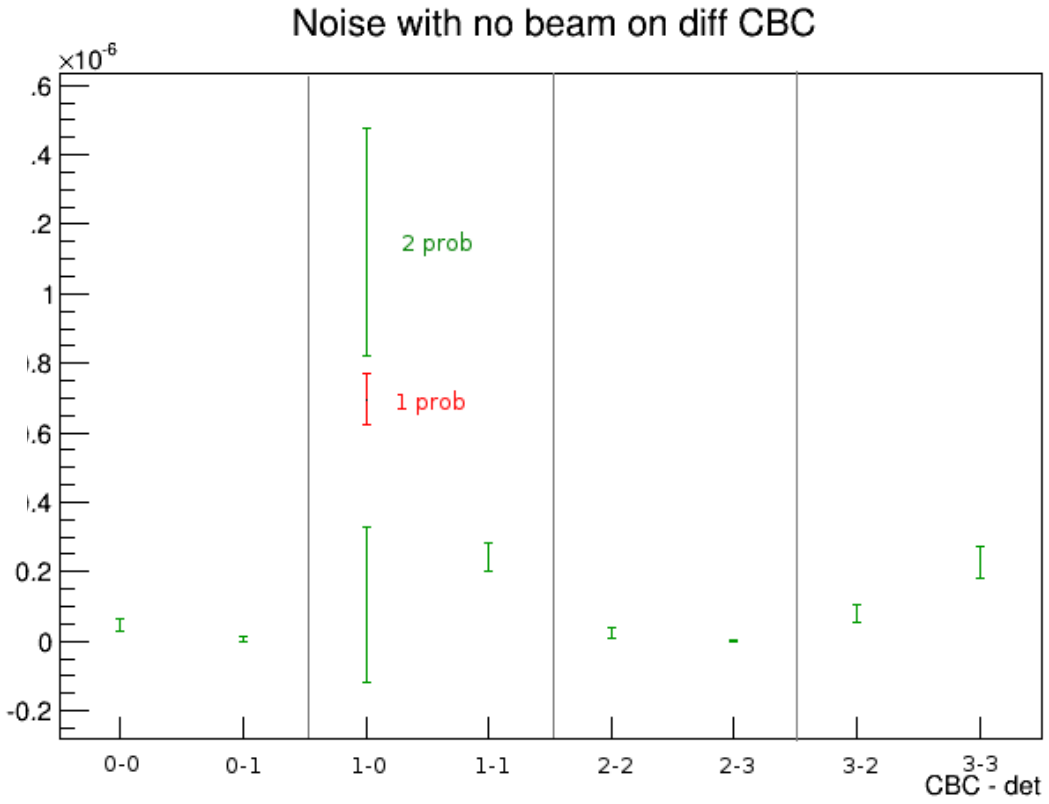
- Average width and cluster width distribution study

- Data used for comparison with CMSSW Digitizer reconstruction
  (Suchandra Dutta and Suvankar Roy Chowdhury, Saha Institute of Nuclear Physics)



Strip noise





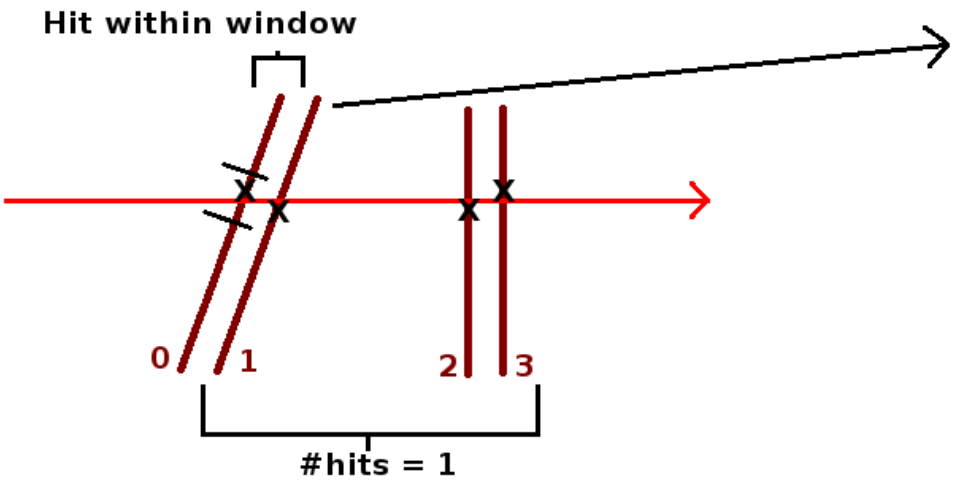
Noise probabilities per CBC and per sensor

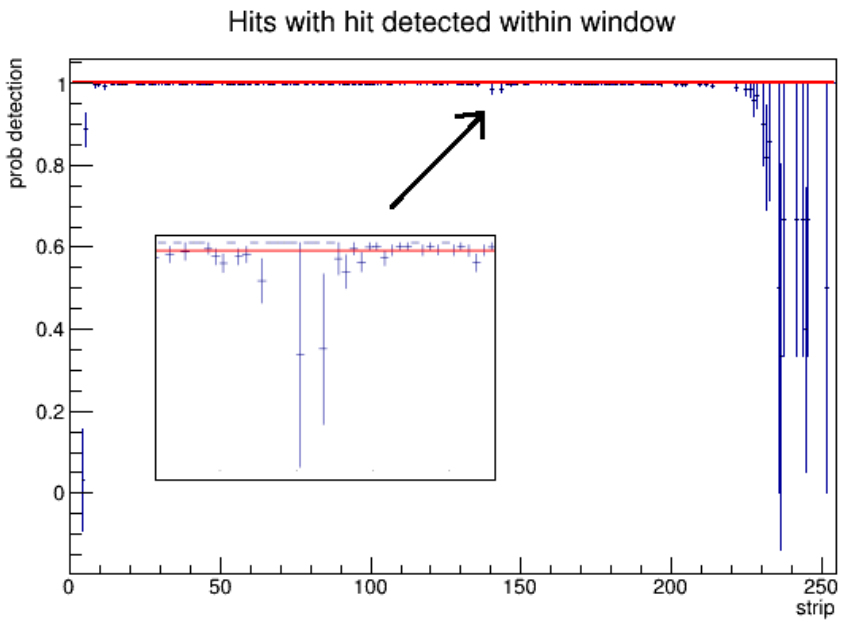
Martin Delcourt,
UC Louvain

- Noise obtained by fitting a binomial to the number of hits per strip with no beam
- One case (CBC1-sens.0) not well described by single binomial → need more data
- Noise smaller than 10^{-6} per strip per trigger

Martin Delcourt,
UC Louvain

Detection Efficiency





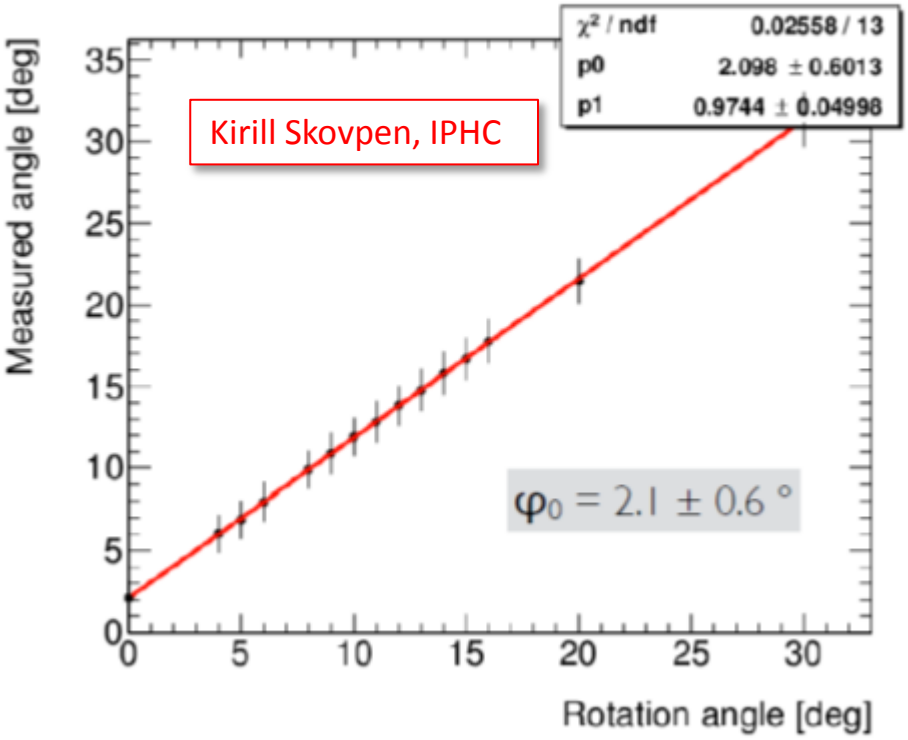
- ε = 99.91±0.01% (CBC0) – 99.89±0.01%(CBC1)
- Loss of efficiency on the sides
- Loss of efficiency in the due to bad strip

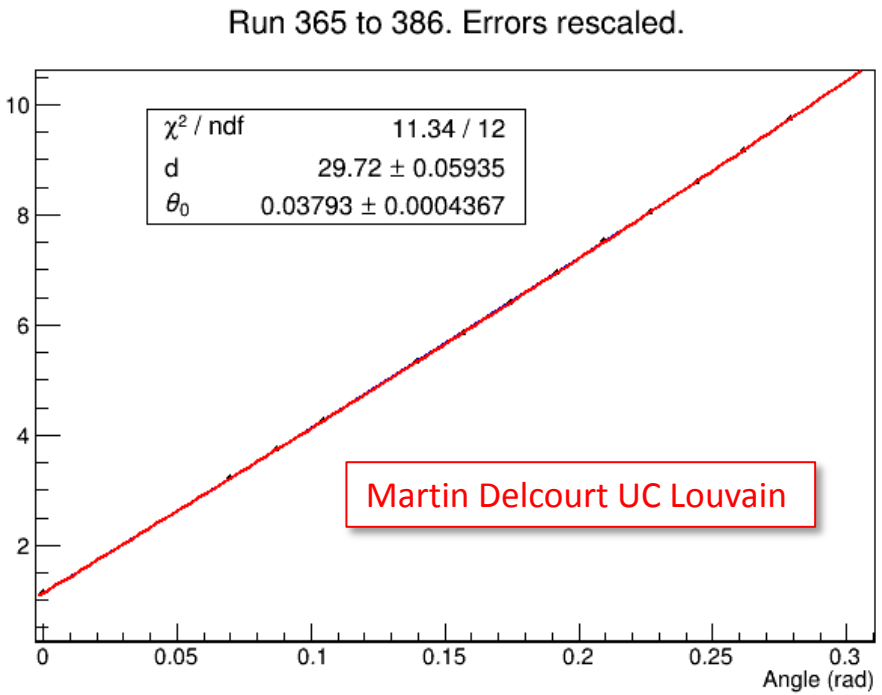
det	CBC	ε(%)	σ_ε
0	0	99.92	0.01
0	1	99.89	0.01
1	0	99.54	0.01
1	1	99.45	0.03
2	2	99.07	0.03
2	3	99.31	0.04
3	2	99.39	0.02
3	3	99.45	0.03

Table : Efficiency of the different sensors/CBC as defined earlier.

Module alignment

Alignment of the rotated module





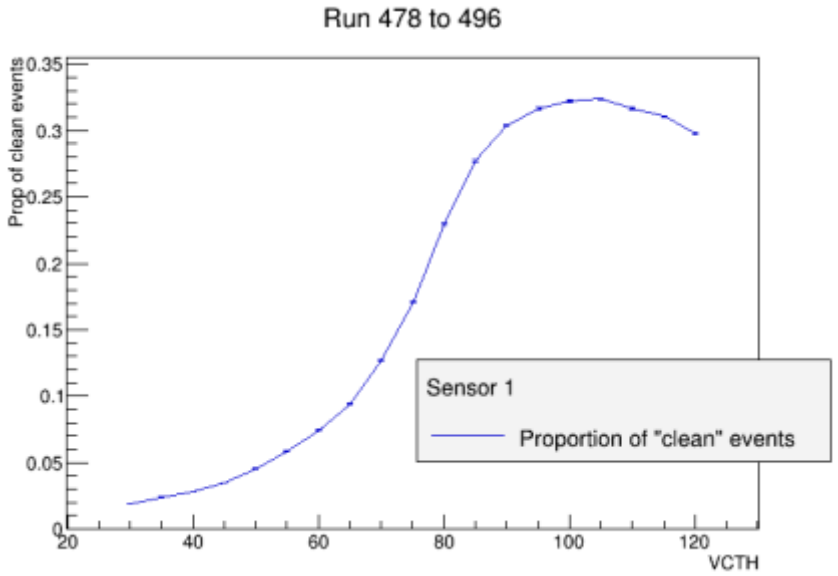
$\phi = 2.1 \pm 0.6^\circ$

$\phi = 2.17 \pm 0.03^\circ$

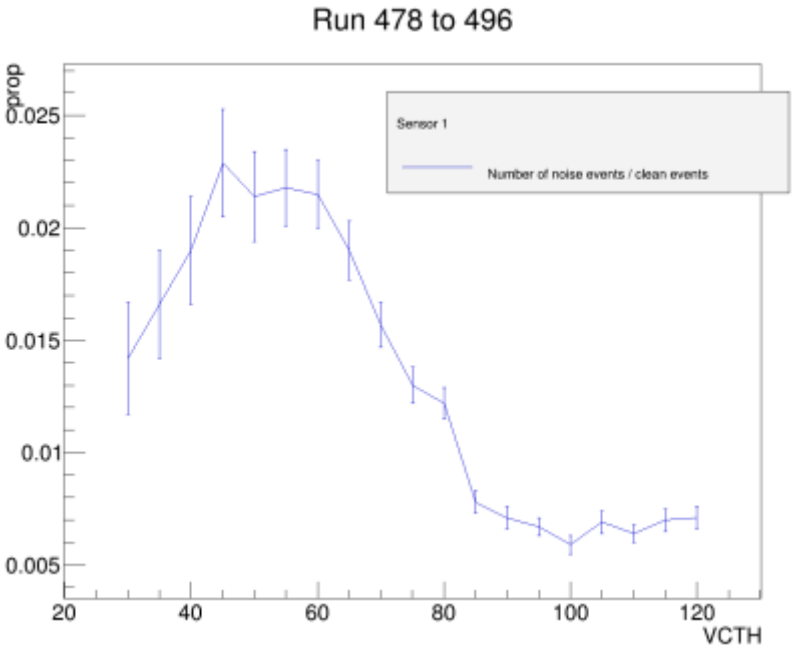
Clean Event Scan

Martin Delcourt
UC Louvain

VCTH ~ 100 optimum setting for low noise and “clean” events



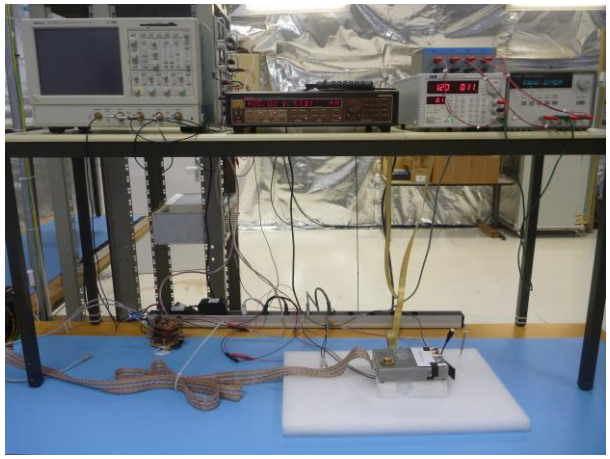
Proportion of events with cluster occupancy = 1 for all sensors.

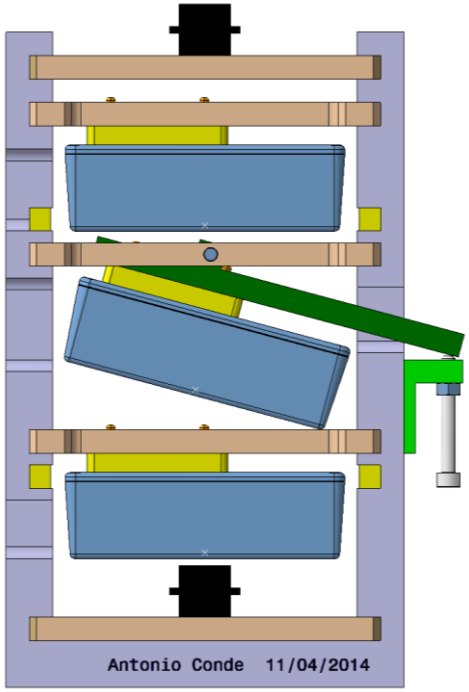


If occ=1 for all sensors, proportion on events with distance > 4 between hits on sensor 0 and sensor 1.

Module-Test Setup at CERN

- Fully equipped Module-Test Setup available at CERN
- exactly the same DAQ chain as in the beam test (FW & SW)
- fully integrated in uTCA shelf
- infrastructure for testing, development & debugging





- mechanics for testing with cosmics / radioactive source & scintillator trigger
- used for: integration tests of components, development of commissioning & calibration procedures
- currently focusing on: CBC hit correlation studies

Georg Auzinger, Stefano Mersi, CERN

Conclusions and Future Work

Conclusions and Future Work

Two successful full-size prototypes of new Outer Tracker ASIC and mini-2S module in hand

- ✓ CBC2 working to specs, stub finding logic functioning

First beam test of the 2S prototype module

- ✓ successful commissioning & readout of two prototype stacked modules in beam, prompt analysis and online s/w
- ✓ data taken for measurement of sensor/front-end performance & to demonstrate ability of 2S modules to discriminate on pT
- ✓ DAQ and readout system integrated, commissioned & working in beam test

TID testing started, no problem so far

Goals for 2014:

- ✓ Continue Pt Module characterization in beam (sensor + front-end ASIC + hybrid + DAQ)

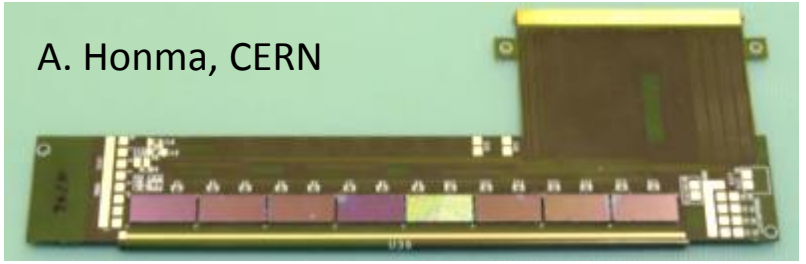
→ Applied for beam time at the end of the year at SPS

→ First characterization of irradiated sensors (cooling required)

- ✓ 8-CBC2 hybrids for the telescope planes

→ Validation of full DAQ chain, including future ASIC (Concentrator) emulated in FPGA

First results to prove the track-trigger concept → CMS ambitious plans for a track trigger look promising



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